HOLOGRAPHIC DEFORMATION ANALYSIS OF THE HUMAN FEMUR

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Abstract-**The deformations of the neck and head of the human dried femur were measured and analyzed with loads applied at the femoral head. Particular attention was paid to measurements of bones with osteoporosis.**
We used double exposures or real-time holographic interferometry to measure precisely. The distal part of each femur was embedded in super hard plaster, and the load was applied at the femoral head. In order to better simulate the situation of a femur under physiological muscles, we used the 3D finite element method (FEM) for our analyses. After modeling the femur, which consisted of meshing as eight noded elements for each section of diaphysis, we used the 3D FEM to calculate stress and strain. We obtained the following results : (1)the deformations increased with the progress of osteoporosis;(2) femur with osteoporosis showed obvious rotational components in the femoral shaft and (3) a compressive stress distribution could be found at the medial side of the diaphyseal region by using the FEM.
Keywords - **Biomechanics, Real Time Holographic Interferometry, Femur, FEM**

I. INTRODUCTION

The femoral neck and its head may experience complicated deformation if they are subjected to force, because the shape and the change of bone density with advanced age are complex. It is well known that falling down or even small external forces can cause a fracture of the femoral neck in the case of elderly persons . In this study, the deformations of the neck and head of the human dried femur were measured and analyzed with loads applied at the femoral head. We used x-ray inspection to select normal, faultless dried adult human femora, some of which had osteoporosis , for our measurements. We simulated the reality of a femur under physiological muscle stress by using the 3D finite element method (FEM) for our analyses..

II. MATERIALS AND METHODS

A. *Optical system*

Figure 1 shows the optical system used for the recording and reconstruction of the real-time hologram 1 . In the figure, the light wave derived from the Ar laser is divided into two waves (IL and R), as shown in the figure by the half mirror (HM). The wave IL illuminates the femur(O), and its reflected wave reaches the thermoplastic film (H) of the process camera (TPC 200, Steinbichler Optotechnik). The reflecting wave at the half mirror (HM) illuminates the film directly through the density filter (D) and the lenses (L). The reflected wave from the object and the reference wave are superimposed on the thermoplastic film. The displacement of the neighboring interference fringe corresponds to 0.26 m.

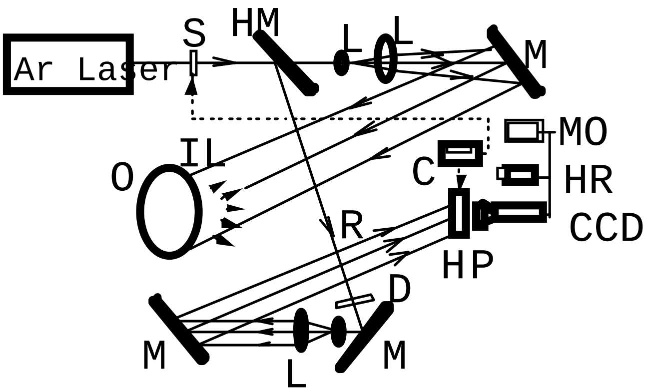

Fig.1 Setup for measuring deformation of the object.
O: Skull, IL: Illuminating wave, R: Reference wave, M: Mirror, L: Lens, HM: Half Mirror, D: Density filter, P: Process camera for thermoplastic film, S: Shutter, H: Hologram recorded on the thermoplastic film , C: Controller for the processing camera, HR: Hard-copy printer, MO: Monitor, V: CCD camera.

B. Thermoplastic recording process

The first step in the production of a hologram is charging the thermoplastic film. The holographic picture can be completed in a matter of seconds, fully automatically, at the touch of a switch by the controller (C) of the process camera (P). The course of a test can be followed on a monitor (MO) by the real-time method immediately after an exposure. Exposure time is set on the controller, and the light wave from the laser is passed to the optical system when the shutter (S) is opened. The thermoplastic film is developed automatically, and 3 seconds after exposure the test result is displayed on a video monitor. The reconstruction image can be recorded on a video tape through the CCD camera. The photo is produced in hard copy on a printer (HR) if necessary. When a load is applied on the point of the femur, the real-time holographic interferogram of the deformation is observed through the monitor.

C. Specimens

We used x-ray examination to select six dried adult human femora for our study. To fix the femur securely in place, we used precision block-type boxes filled with super hard plaster, as shown in Fig. 2. The bones were cut transversely above the femoral condyles, and then they were embedded at

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5 cm under the lesser trochanter before the plaster solidified, so that the diaphysial long axis was inclined medially 20°.The loading method is also shown in Fig. 2.

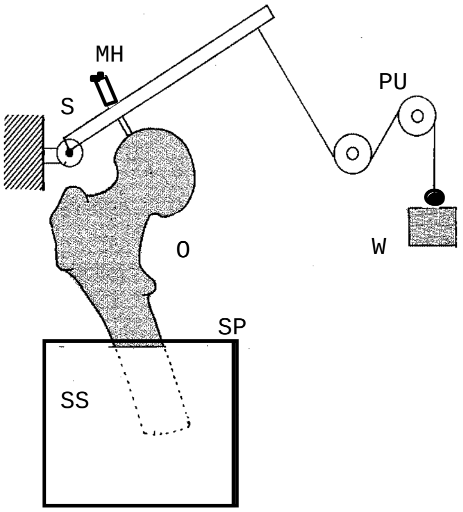

Fig. 2. The method for applying load on the specimen. S: fulcrum, PU: pulleys, SS: Super hard plaster poured in the box-type block (SP), O: femur, W: weight, MH: head of micrometer.

The end of the rod was held at the fulcrum. Its other end was subjected to tension force by weight through its thread. The fulcrum was located near the loading point by means of a micrometer head, as shown in the figure. Its point was located so that the bone was subjected to a load six times its weight. The amount and direction of the load were easily changeable by the loading system. The amounts of loads were set from 1.5 N to 36.0 N, and loading was applied to the femoral head through its center. The directions of loads ranged from 0°to 40° for the anterior and posterior directions in the sagittal plane. The directions of loads in the frontal plane were varied in the same manner for the lateral and medial directions.

III.EXPERIMENTAL RESULTS

A. Deformation of femur due to different load conditions

Figure 3 shows the reconstruction images representing the deformations of the femur. The left and right photographs show the images obtained from the frontal and medial views, respectively. In Fig. 3(a) and (b), the amount of load was 24.0 N, and the loading directions were parallel with the frontal plane and made an angle of 40°from the lateral and medial directions for the vertical axis, respectively. In Fig. 3(a), considering its shape and the appearance of the interference fringes on the proximal part of the femur, we observed that the head of the femur was deformed in the direction having bending component toward the frontal direction and rotation component around the diaphysis. In the images of medial

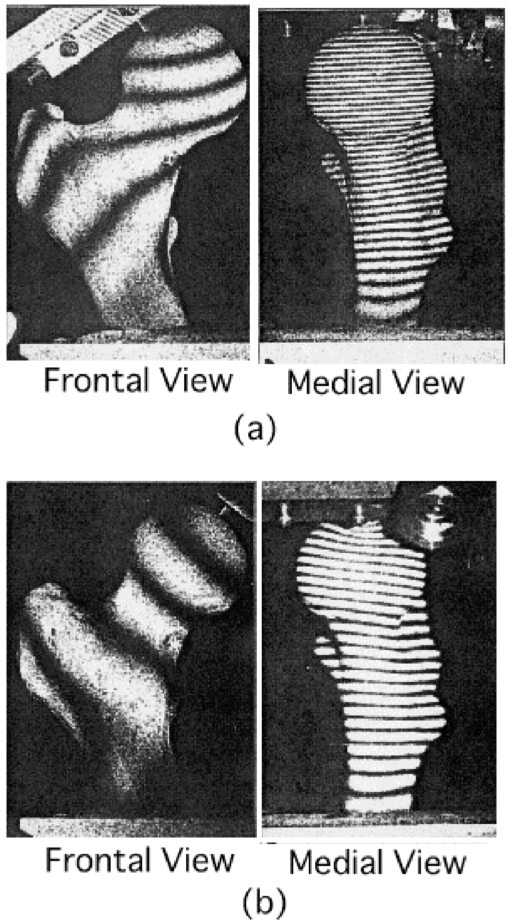

Fig.3 Reconstruction images representing the deformations of femur, when the forces(24.0N) were applied at the lateral(a) and medial(b) points which make an angle of 40°for vertical axes.

views, the density of fringes is greater in image (a) than in image (b). This shows that the proximal part of the femur is more easily deformed by force subjected from the lateral direction than from the medial direction. The moment is greater with force applied from the lateral side, because the moment arm is longer on that side, as shown in Fig. 4.

B. The relation between deformation and degree of osteoporosis

The three femora with comparable head sizes were selected to examine the relation between deformation and degree of osteoporosis. X-rays of the three femora are shown in Fig. 5. The degree of osteoporosis is extreme in specimen (a). The right-hand images show the deformation obtained for each specimen, when a 24.0N load was applied to the head at an

angle of 40°between the posterior direction and the vertical axis. The images were observed from the frontal direction.The highest density of interference fringes is shown in Fig. 5(a). The inclination of displacement at the femoral neck is the largest in specimen(a), which indicates that this

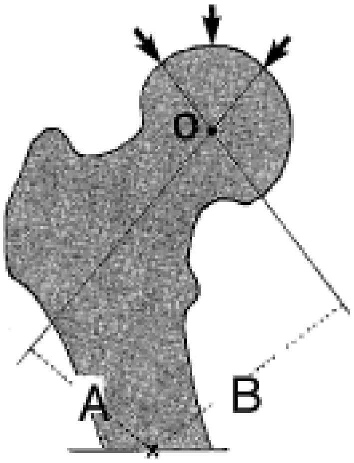

Fig. 4 The relation between the direction of force and the moment arm. The moment arm A is smaller than the moment arm B. O: the center of femoral head .

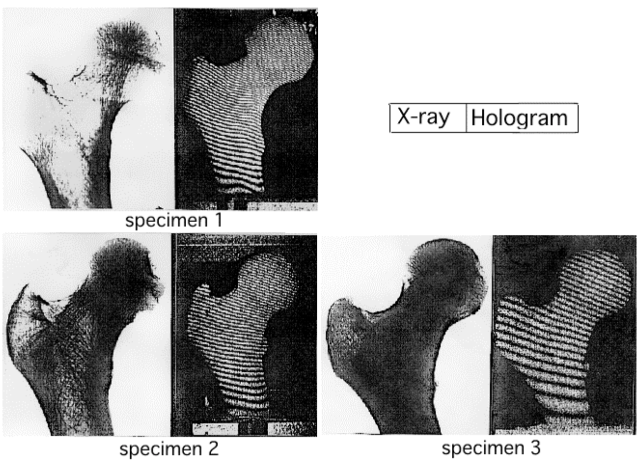

Fig.5 Reconstruction images representing the difference of deformation between the femora with and without osteoporosis. The progresses of osteoporosis show that specimen 1 is most serious from the density of x-ray.

femur had extreme osteoporosis. The femur was bent forward and rotated about the neck of the femur.

B. The relation between deformation and degree of osteoporosis

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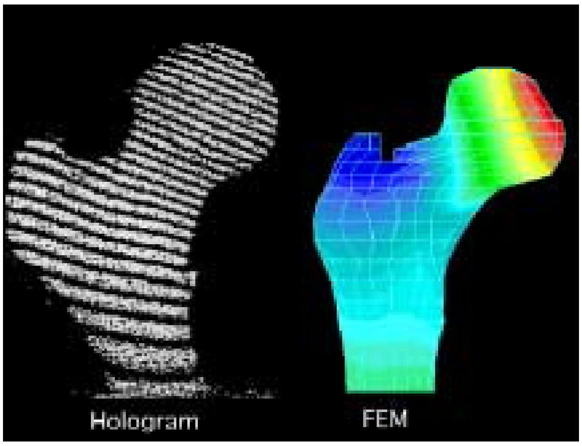
C. The finite element analysis

The finite element method (FEM) 2 was applied to study the stress and strain distribution of the femur by the application of physiological muscle loads and the joint reaction force. The finite element model was generated consisting of eight noded elements. The geometry and the material properties of the bone were decided from the shape obtained from each section from the proximal portion to the diaphysis. Figure 6 shows an example of the obtained results, when a 24.0N load was applied to the head from the posterior direction at an angle of 40°from the vertical axis. The experimental and analytical results were resemble in distribution of displacements.



(a) (b)

Fig. 6 Comparison of displacement as measured by our experiment (a) and by the FEM (b).

IV.SUMMARY

In this study, the deformations of the dried human femur due to static load were analyzed. The following results were obtained: (1) the deformations increased with the progress of osteoporosis; (2) femurs with osteoporosis showed obvious rotational components in the femoral shaft and (3) a compressive stress distribution could be found at the medial side of the diaphyseal region by using the FEM.

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